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(71) Applicant (*for all designated States except US*): STICHTING FMLC [NL/NL]; Kluyverweg 1, NL-2629 HS Delft (NL).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): ROEBROEKS, Geerardus, Hubertus, Joannes, Jozeph [NL/NL]; Bommelsedijk 2, NL-3258 LB Den Bommel (NL). GUNNINK, Jan, Willem [NL/NL]; Groene Dijk 245, NL-2911 BB Nieuwerkerk a/d IJssel (NL).

(74) Agents: VAN DEN HEUVEL, Henricus, Theodorus et al.; Patentwerk BV, P.O. Box 1514, NL-5200 BN 's-Hertogenbosch (NL).

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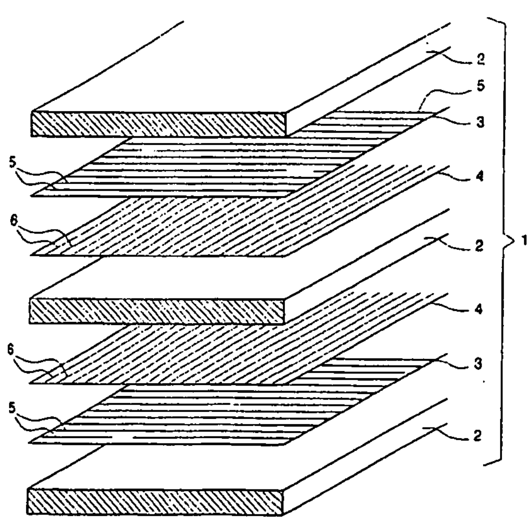

(57) Abstract: Laminate of at least two plates formed from an aluminium alloy, each with a thickness of less than 1 mm, between which is situated an intermediate layer on the basis of plastic which contains at least two groups of continuous, mutually parallel fibres and is connected to the metal plates. The fibres of two different groups intersect perpendicularly and are selected in pairs from aromatic polyamide, glass and carbon, of which the modulus, the tensile strength, the elongation at break and the density must lie within a determined range.

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LAMINATE OF METAL PLATES AND INTERSECTING FIBRE LAYERS

The invention relates to a laminate of at least two plates formed from an aluminium alloy, which each have a thickness of less than 1 mm and between which is situated an intermediate layer on the basis of plastic which contains at least two groups of preferably continuous, mutually parallel fibres and is connected to the metal plates, and the fibres of two different groups intersect, preferably at an angle of about 90°C, wherein the fibres have a modulus of elasticity of at least 50 GPa. The invention further comprises the application of such a laminate as skin plating for the body of an aviation or space craft.

Such a laminate is known from, among others, NL 8100 087 and NL 8100 088. Only one type of material is herein applied for the material of the reinforcing fibres in one laminate and this is chosen from aromatic polyamide, in particular polyparaphenylene terephthalamide, carbon or glass. The intersecting fibres are herein arranged mostly in the form of a woven material, wherein the warp and the weft of the woven material consist of fibres of the same material. Although good results are achieved with the known laminates stated in the preamble, it has been found that these known laminates are not optimal under all conditions. In particular the high and special demands made in aviation and space travel of the skin plates for the body cannot always be completely satisfied with the known laminates.

It is noted that a laminate of another type is described in GB 2 151 185. Here a number of resin-impregnated layers of mutually parallel (unidirectional-UD) fibres, for instance of carbon, are arranged on a substrate formed by a metal plate, which forms a main stack. In the different layers with reinforcing fibres the fibres extend in the direction of the main axis of the load (0°direction). An auxiliary or transition stack is herein arranged between the main stack of reinforcing layers and the substrate. In the transition stack are situated a number of UD-reinforcing fibre layers with fibres at angles of ±15°, ±30° and ±45°, in order to keep the shear stress peaks in the boundary adhesive layer on the metal plate within the elastic range. This results in a complicated and expensive laminate which can be loaded substantially in only one direction.

In US 4 460 633 a non-woven reinforcing element for a plastic plate is described. The reinforcing element is formed from twined reinforcing threads of carbon, glass or aromatic polyamide extending in the warp direction which do not contain any adhesive for their bonding to weft fibres which do contain an adhesive. Examples are described in this publication wherein the yarns in the warp and the weft direction consist of different materials. Particularly in example 1 there is mentioned the combination with carbon fibres in the warp direction and glass fibres in the weft direction, while in example 2 the combination is mentioned of aramid fibres in the warp direction and glass fibres in the weft direction. In the described reinforcing elements the quantity of fibre material in the warp direction is much greater (for instance 96% by weight) than in the weft direction. From a number of the stated reinforcing elements, with their warp directions parallel, a plate-like composite is manufactured by means of lamination and after impregnation with a plastic. This results in a composite which can be loaded in substantially only one direction and which is furthermore less suitable for particular applications due to the absence of a metal covering on the outer sides.

In DE-3 702936 a multi-directional fibre laminate is described with fibres, for instance carbon fibres, in the directions 0°, +45°, -45° and 90°. The fibres in the 0° and/or 90° direction have a high tensile strength and elongation at break, while the fibres in the +45° and -45° directions have a high rigidity and modulus of elasticity. Particularly due to the absence of a metal covering on the outer sides, this known multi-directional fibre laminate will be less suitable for different applications.

In GB 1364076 a laminate is described which is constructed from two plates, for instance consisting of titanium, having therebetween a number of resin-impregnated layers of unidirectional reinforcing fibres. The fibres of successive layers form an angle of 60° with each other. The fibres can for instance consist of glass, carbon or boron. It will clearly be difficult with this known laminate to comply with the special requirements laid down for determined panels for an aircraft.

Described in EP 0 355 912 is a sandwich panel which has a core which is for instance formed by a honeycomb structure and to which panel a fibre-reinforced skin layer is adhered on both sides. Each skin layer can be constructed from two mutually intersecting fibre layers, wherein the layers on the core side are relatively rigid and the

layers on the outer side are relatively tough. Carbon, glass, aramid, ceramic and thermoplastic materials are mentioned as the fibre materials. Particularly due to the absence of a metal covering on the outer sides, this known sandwich panel will be less suitable for different applications.

In US 4 029 838 is described a laminate wherein between metal foils consisting of titanium there are arranged layers which can generally contain fibres of different materials. Titanium in particular is difficult to process and therefore not very attractive for aircraft construction.

Reference is further made to the article "Fatigue behaviour of carbon fiber-reinforced aluminium laminates" by C.T. Lin, P.W. Kao and F.S. Yang on page 135-141 of Composites, part 22, number 2, March 1991. Described here are laminates which substantially consist of two aluminium plates with a thickness of 1 mm, between which are arranged 1-6 unidirectional prepregs of carbon fibres of the T-300 type from Toray, with a relatively low tensile strength of 3530 MPa, impregnated with epoxy resin. A woven glass material impregnated with epoxy resin is herein arranged between the prepregs of carbon fibres and the aluminium plates in order to reduce disadvantageous residual stresses resulting from thermal treatment. As a result of the relatively thick aluminium plates of 1 mm thickness, the delamination areas around fatigue cracks in the laminate will become too large. In addition, the use of 1 mm thick aluminium plates will soon result in a laminate with a relatively great total thickness and weight, which is usually a drawback for applications in the aviation industry.

The invention has for its object to provide a laminate of the type stated in the preamble, whereby it is more readily possible to comply with the high demands made in the aviation and space travel industries. The laminate according to the invention is hereby characterized in that a plurality of types of fibre are applied in the laminate, said fibres being formed from different materials, the following properties of which lie between the following limits:

Modulus of elasticity	70 - 1000 GPa

Tensile strength	2500 - 85000 MPA
Elongation at break	0.3 - 6.0%
Density	1.2 - 2.8g/cm^3.

More preferably the fibres are formed from different materials which are selected from the following group of materials: aromatic polyamide (aramid), glass, carbon, M5 and Zylon, the following properties of which lie between the following limits:

	Fibres of aromatic polyamide	Fibres of glass	Fibres of carbon
Modulus of elasticity (GPa)	110-160	70-110	220-1000
Tensile strength (MPa)	2500-5000	3800-12000	4500-8500
Elongation at break (%)	1.7-3.6	3.8-11.0	0.3-3.5
Density (g/cm^3)	1.2-1.6	2.3-2.8	1.6-2.0.

For M5 it is the case that the modulus of elasticity can vary between 250 and 350 GPa, the tensile strength is variable between 3000 and 5000 MPa and the elongation at break between 1.2 and 1.8%, while for Zylon it is the case that the electricity modulus can vary between 150 and 300 GPa, the tensile strength is variable between 5000 and 7000 MPa and the elongation at break between 2.0 and 4.0%. The laminate can comprise intersecting fibres formed from different materials and/or parallel fibres formed from different materials.

According to the invention the fibres are preferably formed by continuous, practically endless filaments with a diameter of 3 to 25 μm, which are applied in the form of fibre or filament bundles or yarns. According to the invention the number of metal plates amounts to 2-20, preferably 2-5, and the metal plates must have a tensile strength of at least 0.20 GPa. According to the invention the metal plates consisting of an aluminium alloy can be selected particularly from the following group of materials: Aluminium alloys, such as of the type AA(USA) No. 2024 or AA(USA) No. 7075 or AA(USA) No. 7475 or AA(USA) No. 6013. In order to avoid delamination, the metal plates must be connected to each other with a suitable type of adhesive, which can be realized according to the invention in that each fibre-containing intermediate layer contains a matrix of a material formed substantially by a thermo-setting plastic such as epoxy

resin, unsaturated polyester resin, vinyl esters or phenol resins, or a matrix of a thermoplastic plastic.

The plastic in the intermediate layer can optionally also be formed by a thermoplastic plastic. In the first place a practically amorphous thermoplastic plastic can be applied for this purpose according to the invention with a glass-transition temperature Tg higher than 140°C, preferably higher than 160°C, such as polyarylate (PAR), polysulphone (PSO), polyethersulphone (PES), polyether imide (PEI) or polyphenylene ether (PPE), in particular poly-2,6 dimethyl phenylene ether. According to the invention a semi-crystalline or para-crystalline thermoplastic plastic can also be applied with a crystalline melting point Tm higher than 170°C, preferably higher than 270°C, such as polyphenylene sulphide (PPS), polyether ketones, in particular polyether ether ketone (PEEK), polyether ketone (PEK) and polyether ketone ketone (PEKK), "liquid crystal polymers" such as XYDAR from Dartco, composed of the monomers biphenol, terephthalic acid and hydrobenzoic acid.

According to the invention a laminate which can be manufactured in simple and economic manner is characterized in that the fibres of intersecting groups extend in linear, i.e. unidirectional, manner and are not held in woven form. In order to prevent warping of the laminate as a result of internal stresses, the laminate according to the invention can be constructed symmetrically relative to a plane through the middle of the thickness of the laminate. A recommended embodiment of the laminate is characterized according to the invention in that the thickness of each of the metal plates amounts to 0.1 to 0.9 mm, preferably 0.2 to 0.5 mm. in order to limit galvanic corrosion, the laminate according to the invention can be embodied such that a layer of electrically conductive fibres, such as carbon fibres, is covered on each side with a layer of electrically non-conductive fibres, such as glass or aramid fibres, intersecting the conductive fibres.

An effective embodiment of the laminate is characterized according to the invention in that it is formed by three metal plates and that at least two groups of intersecting fibres of different materials are situated in the intermediate space between each pair of plates. The laminate according to the invention is here further characterized in that the fibres

form 35-75 % by volume, in particular 40 to 65 % by volume, of the total volume of the matrix of plastic and fibres together.

A rectangular plate of the laminate according to the invention is hereby advantageously characterized according to the invention in that the fibres of the one group of the one material extend parallel to the one side of the rectangle and that the fibres of the other group of the other material extend parallel to the other side of the rectangle of the plate. It is noted here that the plate can take a flat form but may also take a single-curved or double-curved form, which is for instance possible by laminating them on a correspondingly shaped mould.

The laminates according to the invention are particular suitable for forming the skin plates for the body of an aircraft or space craft. The invention also comprises an aircraft or space craft whose body is wholly or partly constructed from skin plates of the laminates according to the invention, wherein the skin plates are arranged such that the fibres of the one group extend in the peripheral direction of the body and that the fibres of another group extend in longitudinal direction of the body.

According to the invention a laminate is obtained which particularly meets four important requirements. These are, firstly, good fatigue properties in two mutually perpendicular directions which correspond with the directions of said perpendicularly intersecting fibres of different materials with different properties. Secondly, a great strength in the direction of the fibres with the greatest strength. Thirdly, the greatest possible thickness to increase the resistance against buckling in combination with a lower weight (kg/m^2) than a solid aluminium plate. Fourthly, an optimal rigidity of the laminate. From the laminates according to the invention which meet the stated requirements can be obtained a new body material for an aircraft, which fulfills three special requirements made of the body, i.e. firstly, good fatigue properties in transverse and longitudinal direction of the body. Secondly, great strength in peripheral direction of the body. Thirdly, the greatest possible thickness to increase the resistance against buckling, but with a lower weight (kg/m^2) than a solid aluminium plate. An advantageous body material according to the invention can be obtained with the application of, among others, two types of laminate A and B.

In addition to the metal plates, laminate type A contains perpendicularly intersecting fibres of continuous, i.e. practically endless, filaments of PPDT and glass. The PPDT fibres must herein extend in longitudinal direction of the body, and the glass fibres, which have a greater tensile strength than the PPDT fibres, must extend in peripheral direction of the body.

In addition to the metal plates, laminate type B likewise contains intersecting fibres of continuous filaments of glass and carbon. The rigid carbon fibres must then extend in the longitudinal direction of the body, wherein they somewhat relieve the load on the stiffeners fixed to the body skin, while the glass fibres extend in peripheral direction of the body. In this direction the glass fibres give the body the high damage tolerance which is so characteristic for laminates in which fibres with high elongation at break are used.

The invention will be further elucidated with reference to the schematic drawing.

Figure 1 shows a laminate with three metal plates.
Figure 2 shows the construction of the laminate according to figure 1.
Figure 3 shows another embodiment of the laminate according to figure 1.
Figure 4 shows a laminate with two metal plates.
Figure 5 shows a laminate with four metal plates.
Figure 6 shows a laminate with five metal plates.
Figure 7 shows another embodiment of the laminate of figure 5, likewise with four metal plates.
Figure 8 shows a cylindrical part of a body constructed from laminates according to the invention.
Figure 9 shows the curve of the crack growth under varying load for a known laminate and a laminate according to the invention.
Figure 10 shows the curve of the residual strength at different stress concentration factors for a known laminate and a laminate according to the invention.

Figure 1 shows an embodiment of laminate 1 according to the invention in the form of a rectangular flat plate. For the purpose of elucidating the assembly, the different parts from which laminate 1 is constructed are drawn at some distance from each other in

figure 2. Laminate 1 is constructed from three metal plates 2 with a thickness of for instance 0.3 mm, which consist of an aluminium alloy. The three metal plates 2 are fixedly connected to each other in identical manner using an intermediate layer on the basis of plastic, such as epoxy resin, which is also a suitable metal adhesive. The intermediate or connecting layer contains and is formed from two fibre layers or prepregs 3 and 4 impregnated with said plastic. The layers 3 with a thickness of for instance 0.15 mm are formed from a mutually parallel (unidirectional) group of glass fibres 5, and the layers 4 with a thickness of for instance 0.22 mm are formed from a group of mutually parallel (unidirectional) PPDT fibres 6. Each of the fibres 5 and 6 consists of a bundle of a large number of, for instance 1000, untwined, continuous, i.e. practically endless, filaments which each have a diameter of 3-25 µm. As shown, the fibres 5 and 6 from the two layers or groups 3 respectively 4 intersect perpendicularly, while because of their different composition, i.e. glass or PPDT, these fibres moreover have different properties in respect of tensile strength, modulus of elasticity, elongation at break and density among others.

Figure 3 shows a laminate 7 according to the invention in cross-section, wherein corresponding parts are designated with the same reference numerals. Just as laminate 1, laminate 7 is constructed from three metal plates 2. The two connecting layers between plates 2 are each formed from three plastic-impregnated fibre layers or prepregs 4 and 8. The layers 4 once again each consist of a group of a large number of mutually parallel PPDT fibres (not shown). Layer 8 is formed by a group of a large number of mutually parallel carbon fibres (not shown). In each intermediate space between metal plates 2, the layer 8 of electrically conductive carbon fibres is therefore covered on both sides with a layer 4 of electrically non-conductive PPDT fibres.

Figure 4 shows a laminate 9 according to the invention in cross-section, wherein corresponding components are designated with the same reference numerals. Laminate 9 is constructed from just two metal plates 2 with of course only one intermediate or connecting layer. In laminate 9 the connecting layer between metal plates 2 is formed, just as the two connecting layers in laminate 7, from three plastic-impregnated fibre groups or fibre layers or prepregs 4 and 8 of PPDT or carbon fibres.

Figure 5 shows a laminate 10 according to the invention in cross-section, wherein corresponding components are designated with the same reference numerals. Laminate 10 is constructed from four metal plates 2 having therebetween three connecting layers which, as in laminates 7 and 9, are each formed from three plastic-impregnated fibre layers or prepregs 4 and 8 of PPDT or carbon fibres.

Figure 6 shows a laminate 11 according to the invention in cross-section, wherein corresponding components are designated with the same reference numerals. Laminate 11 is constructed from five metal plates 2 having therebetween four connecting layers which, as in laminates 7, 9 and 10, are each formed from three plastic-impregnated fibre layers or prepregs 4 and 8 of PPDT or carbon fibres.

Figure 7 shows a cross-section of a laminate 13, wherein corresponding parts are designated with the same reference numerals. Laminate 13 is constructed from four metal plates 2 with three connecting layers therebetween. The two outer connecting layers are each formed here from one plastic-impregnated fibre layer or prepreg 3 of glass fibres. The middle connecting layer is formed from one plastic-impregnated fibre layer or prepreg 4 of PPDT fibres. For this very effective laminate according to the invention it is also the case that at least two groups of layers 3, 4 of unidirectional fibres are present in each case between two metal plates 2, i.e. a first and a third. In each group or layer the fibres are here mutually parallel, although the fibres of the one group or layer 3 intersect the fibres of the other group or layer 4 perpendicularly.

Figure 8 shows a part of a cylindrical body 14 of an aircraft. Body 14 is assembled from a large number of rectangular skin plates 15 which are fixed to a frame (not shown) and which each consist of a laminate according to the invention, such as for instance laminate 1 of figures 1 and 2. The peripheral direction of the body is indicated with arrows 16, while the longitudinal direction of the body is indicated with arrows 17. In one of skin plates 15 of laminate 1, figure 8 shows schematically the direction of the perpendicularly intersecting fibres. Skin plates 15 are mounted such that said PPDT fibres 6 extend in longitudinal direction 17 of body 14 and said glass fibres 5 extend in peripheral direction 16.

The invention will be further elucidated on the basis of the following examples.

Example I according to the invention.

Here a rectangular laminate of 600 x 600 mm was manufactured from 3 aluminium plates, each with a thickness of 0.3 mm, of the Al-alloy of the type AA(USA) No. 2024. The metal plates must undergo several suitable pre-treatments, such as alkaline cleaning, etching in a chromic acid-sulphuric acid bath, anodizing in chromic acid or phosphoric acid, applying of a primer, for instance on the basis of epoxy phenol (such as Cytec's BR127) with anti-corrosive properties or the like, which is suitable for the type of plastic to be used, before they can be combined with the prepregs. The laminate for manufacturing is of the type shown in figure 3, with the difference that in the intermediate or connecting layers the prepregs of unidirectional (UD) carbon yarns are covered on both sides in each case with a prepreg of R-glass yarns. In all prepregs the fibre volume was 60%. The UD prepregs with carbon yarns consisted of carbon yarns of the brand Tenax®, type IM600, with a filament diameter of 5 μm and, when under strain of tension, a modulus of elasticity of 290 GPa a tensile strength of 5400 MPa and an elongation at break of 1.7% at a density of 1.8 g/cm^3, wherein the carbon yarns were impregnated with an effectively adhesive plastic on the basis of epoxy resin of the type AF163-2, commercially available from 3M Company. The UD prepregs with glass yarns consisted of R-glass yarns of the RA 9041 type, supplied by Vetrotex, with a filament diameter of 10 μm and, when under strain of tension, a modulus of elasticity of 89 GPa, a tensile strength of 4400 MPa and an elongation at break of 5.0% at a density of 2.54 g/cm^3, wherein the glass yarns were likewise impregnated with said plastic AF 163-2. The different constituent parts of the laminate for manufacturing were stacked on a flat table in the required order, i.e.

Al-plate thickness 0.3 mm
R-glass prepreg thickness 0.0625 mm (L-direction)
Carbon yarn thickness 0.125 mm (LT-direction)
R-glass prepreg thickness 0.0625 mm (L-direction)
Al-plate thickness 0.3 mm
R-glass prepreg thickness 0.0625 mm (L-direction)
Carbon yarn prepreg thickness 0.125 mm (LT-direction)
R-glass prepreg thickness 0.0625 mm (L-direction)
Al-plate thickness 0.3 mm.

The L-direction and the LT-direction form angles of 90° with each other. The glass yarns (L-direction) run parallel to the long sides of the rectangle of the Al-plates which coincide with the rolling direction of the plates. The carbon yarns (LT-direction) therefore run parallel to the short sides of the rectangle of the Al-plates. The thus stacked laminate from separate, parallel components, i.e. 3 aluminium plates with a total 6 prepregs therebetween, was covered with foil on the support. The laminate, packed in foil and still consisting of separate components, was then compressed from the outside by applying a vacuum in the packing of the laminate. The packed laminate was placed in an autoclave for curing of the epoxy resin. In the autoclave the laminate was first heated to a temperature of 125°C at a speed of 3°C per minute. After heating, the laminate was kept in the autoclave for 1 hour at the temperature of 125°C and a pressure of 6-10 Bar. The cooled laminate was <u>not</u> pre-stressed. The total thickness of the completed laminate was 1.4 mm. The value of the modulus of elasticity of the thus manufactured laminate 1 according to the invention was determined at E_{LT} = 79.14 GPa when under strain of tension in the LT-direction of the carbon fibres.

<u>Example II</u> not according to the invention.

For comparison with Example I, a laminate was made according to Example II in the same manner, the only difference being in the prepregs applied. The stack of separate parts of the laminate for manufacturing according to Example II had the following composition on the flat table:

Al-plate thickness 0.3 mm
R-glass prepreg thickness 0.125 mm (L-direction)
R-glass prepreg thickness 0.125 mm (LT-direction)
Al-plate thickness 0.3 mm
R-glass prepreg thickness 0.125 mm (LT-direction)
R-glass prepreg thickness 0.125 mm (L-direction)
Al-plate thickness 0.3 mm.

The total thickness of this completed laminate was also 1.4 mm. The value of the modulus of elasticity of the thus manufactured, per se known (under the brand name Glare) laminate II according to example II was determined at E_{LT} = 57.6 GPa when under strain of tension in the LT-direction of the glass fibres.

Comparison of the laminates I according to example I and II according to example II therefore shows that laminate I according to the invention has a considerably higher modulus than laminate II of the prior art.

In figure 9 the fatigue behaviour of laminates I and II is compared. For this purpose test pieces of 100 x 300 mm from both laminates are placed under strain of tension in transverse direction (see test piece in figure 9) with a sine-shaped load of 0-120 MPa and a frequency of 10 Hz. The tensile load on laminates I occurred in the direction parallel to the carbon fibres, i.e. transversely of the glass fibres. The tensile load on laminates II occurred in the same direction LT. The test pieces were provided in advance with a sharp saw cut-shaped initial crack transversely of the pulling direction of a length of 2a=3 mm. In figure 9 half the crack length a is plotted in mm along the vertical axis. The total number of cycles of the applied sine-shaped fatigue tensile load is plotted with constant amplitude along the horizontal axis. As can be seen in figure 9, laminate I (line 1) according to the invention has a clearly smaller crack growth under the influence of said load than laminate II (line II) according to the prior art. It can therefore be concluded that the fatigue behaviour of the laminate according to the invention is clearly more favourable than that of the prior art laminate.

In figure 10 the residual tensile strength for laminates I (line I) and II (line II) is determined without and with the presence of determined damage to the laminate in the form of a hole or groove. Test pieces from laminates I and II are subjected for this purpose to a tensile test with the pulling direction perpendicular to the length of said groove. In the test pieces from laminate I the tensile load was applied in the direction parallel to the carbon fibres, so transversely of the glass fibres. In the test pieces from laminates II the tensile load was applied in the direction parallel to one of the two groups of glass fibres, i.e. in the LT direction. The degree of damage to the test pieces was expressed by the stress concentration factor K_t, which is calculated in the manner usual in the art with a formula which only applies when all deformations in the test plate are elastic:

$$K_t = \frac{\Phi peak}{\Phi nominal}, \text{ wherein}$$

Φpeak = the peak stress in the plate material at the end of the irregularity, which can for instance take the form of a circular hole or a groove

Φnominal = the tensile stress at the position of the irregularity calculated from the tensile force divided by the remaining (nominal) area of the cross-section of the test bar at the position of the irregularity.

In figure 10 the residual strength S_{net} found in the tensile tests is plotted in MPa along the vertical axis. S_{net} = the maximum tensile force divided by the remaining (nett) area of the cross-section at the start of the tensile test. Stress concentration factor K_t is plotted along the horizontal axis. In figure 10 the residual strengths for five values of K are determined for laminates I and II, namely $K_t = 1$, $K_t = 2.43$, $K_t = 3.32$, $K_t = 4.74$ and K_t = infinite. At $K_t = 1$ no damage was arranged in the test pieces (which have a width of 12.5 mm). At $K_t = 2.43$ the 100 mm-wide test pieces were provided in the centre with a circular hole with a diameter of 25 mm.

At $K_t = 3.32$ the 100 mm-wide test pieces were provided in the centre with a groove extending transversely of the pulling direction with a length of 25 mm and a width of 10 mm. The rounding-off on both sides of the groove was therefore 5 mm. At $K_t = 4.74$ the 100 mm-wide test pieces were provided in the centre with a groove extending transversely of the pulling direction with a length of 25 mm and a width of 4 mm. At K_t = infinite the test pieces were provided in the centre with a groove in the form of a saw cut extending transversely of the pulling direction with a length of 25 mm and a width of 1 mm. As can be seen from the curve of lines I and II in figure 10, the residual strength of laminates I according to the invention is clearly greater at the different values of K_t than of prior art laminates II.

Everywhere in the description and the claims where reference is made to the modulus of elasticity, the tensile strength and the elongation at break of the fibres, this is understood to mean the values under strain of tension in the longitudinal direction of the fibre and determined by measurement of the completed laminate.

The stated glass transition point T_g of said substantially amorphous thermoplastic plastics must be measured using a dynamic mechanical measuring apparatus of the RDA-700 type manufactured by Rheometrics, at a frequency of 1 Hertz and a heating

speed of a maximum of 2°C per minute. The T_g is the temperature at which the damping modulus G" is maximal.

The stated crystalline melting point T_m of the semi-crystalline, thermoplastic plastics is determined using "Differential Scanning Calorimetry" (DSC). Use is made here of the Perkin Elmer measuring apparatus type DSC-7, applying a heating speed of 20°C per minute. T_m is herein defined as the peak maximum of the endothermic peak in the DSC curve.

Different modifications can be made within the scope of the invention. Although in the first place metal plates of equal thickness are used in the laminates according to the invention, it is in principle also possible to apply metal plates with two or more different thicknesses in an optionally symmetrical formation in one and the same laminate. The layer of plastic between two successive metal plates will generally have a thickness which is of about the same order of magnitude as that of each of the metal plates.

The laminates according to the invention drawn in figures 1-7 are wholly symmetrical relative to a plane through the middle of the thickness of the laminate and parallel to the plane of the metal plates. In addition to the thickness of the metal plates, the thickness of the plastic layers and the number of fibre layers located therein can also be varied in an optionally symmetrical formation. If desired, the plastic layer can contain several standard additions such as a curers, fillers and the like. According to the invention fibres of continuous, practically endless filaments are preferably applied in the laminates. Semi-continuous, i.e. not endless, filaments or fibres with a length of at least 10 mm can however also be applied according to the invention in the laminates. If desired, metal plates 2 formed from an aluminium alloy can be applied in the laminate according to the invention, these plates being reinforced with fibres which are then situated in a matrix of the metal. The laminate according to the invention will generally be embodied such that one of the groups of parallel or unidirectional fibre groups extends in rolling direction of the metal plates. In the laminates according to the invention fibres of glass, which is known commercially under the names R-glass and S2 glass, are preferably used for the glass fibres. For the fibres of PPDT and carbon, fibres are preferably applied which are known commercially by the names Twaron® respectively Tenax®. It is also possible for M5 fibres and/or Zylon® fibres to be applied.

Claims

1. Laminate of at least two plates formed from an aluminium alloy, which each have a thickness of less than 1 mm and between which is situated an intermediate layer on the basis of plastic which contains at least two groups of preferably continuous, mutually parallel fibres and is connected to the metal plates, and the fibres of two different groups intersect, preferably at an angle of about 90°C, wherein the fibres have a modulus of elasticity of at least 50 GPa,
characterized in that a plurality of types of fibre are applied in the laminate, said fibres being formed from different materials, the following properties of which lie between the following limits:

Modulus of elasticity	70 - 1000 GPa
Tensile strength	2500 - 85000 MPA
Elongation at break	0.3 - 6.0%
Density	1.2 - 2.8g/cm^3.

2. Laminate as claimed in claim 1, **characterized in that** the fibres are formed from different materials which are selected from the following group of materials: aromatic polyamide (aramid), glass, carbon, M5 and Zylon, the following properties of which lie between the following limits:

	Fibres of aromatic polyamide	Fibres of glass	Fibres of carbon
Modulus of elasticity (GPa)	110-160	70-110	220-1000
Tensile strength (MPa)	2500-5000	3800-12000	4500-8500
Elongation at break (%)	1.7-3.6	3.8-11.0	0.3-3.5
Density (g/cm^3)	1.2-1.6	2.3-2.8	1.6-2.0.

3. Laminate as claimed in claim 1 or 2, **characterized in that** the laminate comprises intersecting fibres formed from different materials.

4. Laminate as claimed in any of the foregoing claims, **characterized in that** the laminate comprises parallel fibres formed from different materials.

5. Laminate as claimed in any of the foregoing claims, **characterized in that** the fibres are formed by continuous filaments with a diameter of 3 to 25 μm.

6. Laminate as claimed in any of the foregoing claims, **characterized in that** the number of metal plates amounts to 2-20, preferably 2-5, and that the metal plates have a tensile strength of at least 0.20 GPa.

7. Laminate as claimed in any of the foregoing claims, **characterized in that** in each fibre-containing intermediate layer the matrix is formed substantially from a thermo-setting plastic such as epoxy resin, unsaturated polyester resin, vinyl esters or phenol resins.

8. Laminate as claimed in any of the foregoing claims, **characterized in that** in each fibre-containing intermediate layer the matrix is formed substantially from a thermoplastic plastic.

9. Laminate as claimed in any of the foregoing claims, **characterized in that** the fibres of intersecting groups extend in linear, i.e. unidirectional, manner and are not held in woven form.

10. Laminate as claimed in any of the foregoing claims, **characterized in that** the thickness of each of the metal plates amounts to 0.1 to 0.9 mm, preferably 0.2 to 0.5 mm.

11. Laminate as claimed in any of the foregoing claims, **characterized in that** a layer of electrically conductive fibres, such as carbon fibres, is covered on the side of the metal plates with a layer of electrically non-conductive fibres, such as glass or aramid fibres, intersecting the conductive fibres.

12. Laminate as claimed in any of the foregoing claims, **characterized in that** it is formed by three metal plates and that two groups of intersecting fibres of different materials are situated in the intermediate space between each pair of plates.

13. Laminate as claimed in any of the foregoing claims, **characterized in that** in each intermediate layer the fibres form 35-75 % by volume, in particular 40 to 65 % by volume, of the total volume of plastic and fibres together.

14. Rectangular plate of the laminate as claimed in any of the foregoing claims, **characterized in that** the fibres of the one group of the one material extend parallel to the one side of the rectangle and that the fibres of the other group of the other material extend parallel to the other side of the rectangle of the plate.

15. Skin plate for the body of an aircraft or space craft, **characterized in that** the skin plate is formed from a laminate as claimed in any of the foregoing claims.

16. Aircraft or space craft, **characterized in that** the body contains skin plates as claimed in claim 15 which are arranged such that the fibres of the one group extend in the peripheral direction of the body and that the fibres of another group extend in longitudinal direction of the body.

1/5

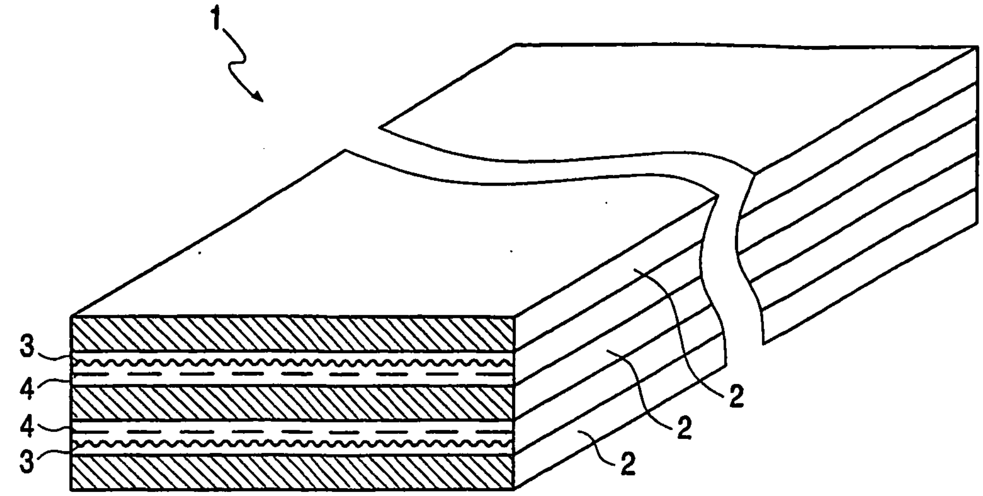


FIG. 1

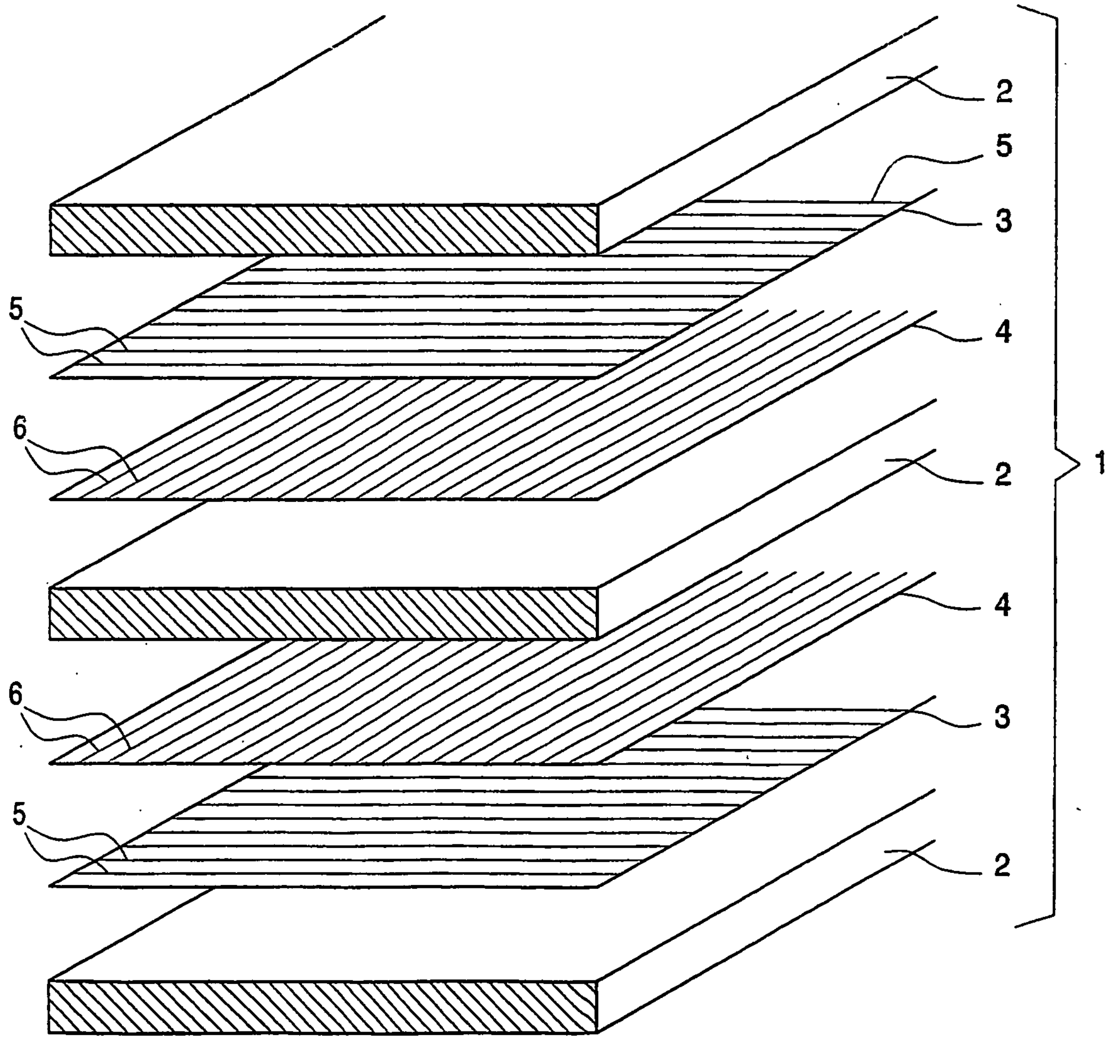


FIG. 2

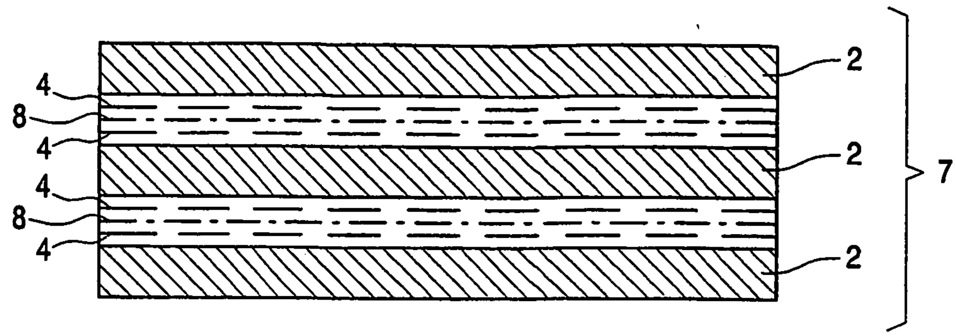


FIG. 3

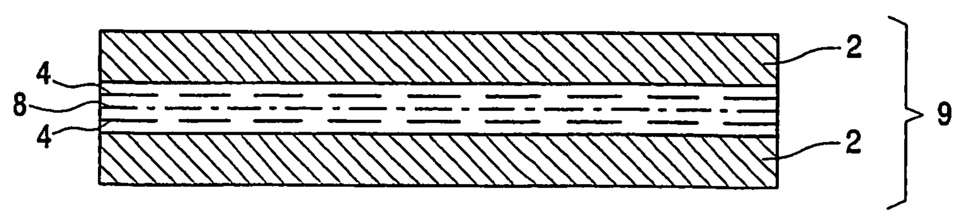


FIG. 4

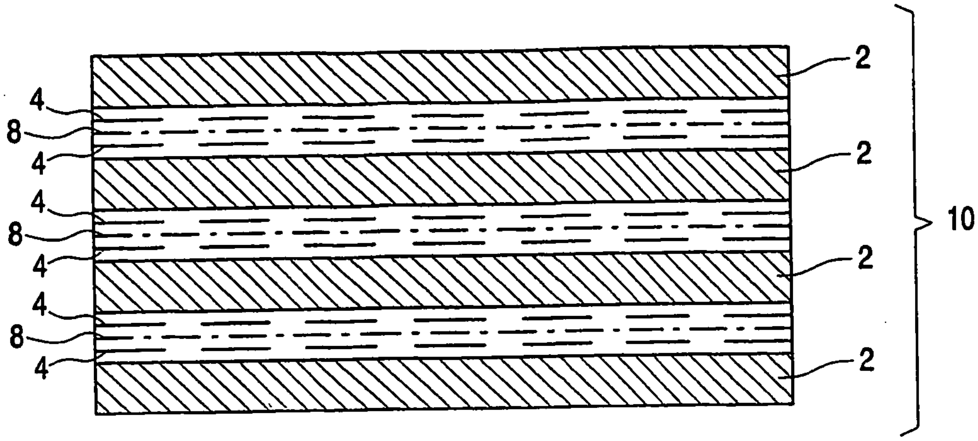


FIG. 5

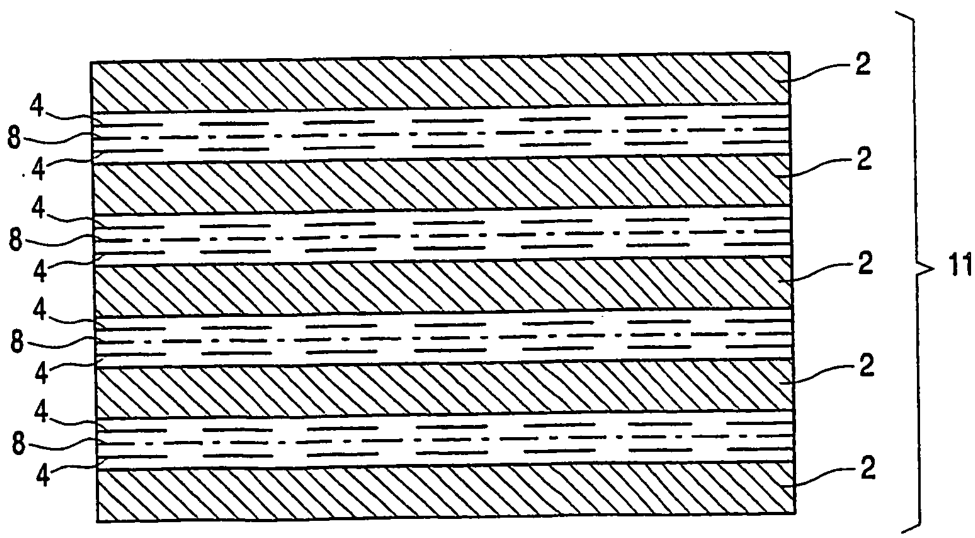


FIG. 6

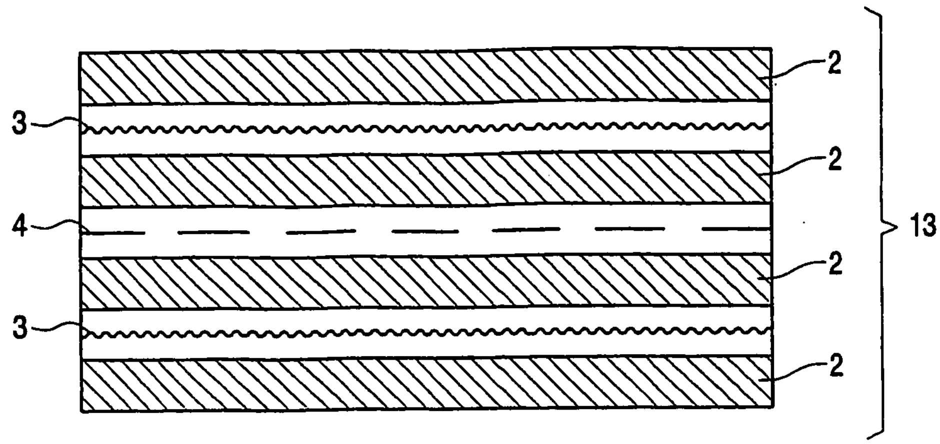


FIG. 7

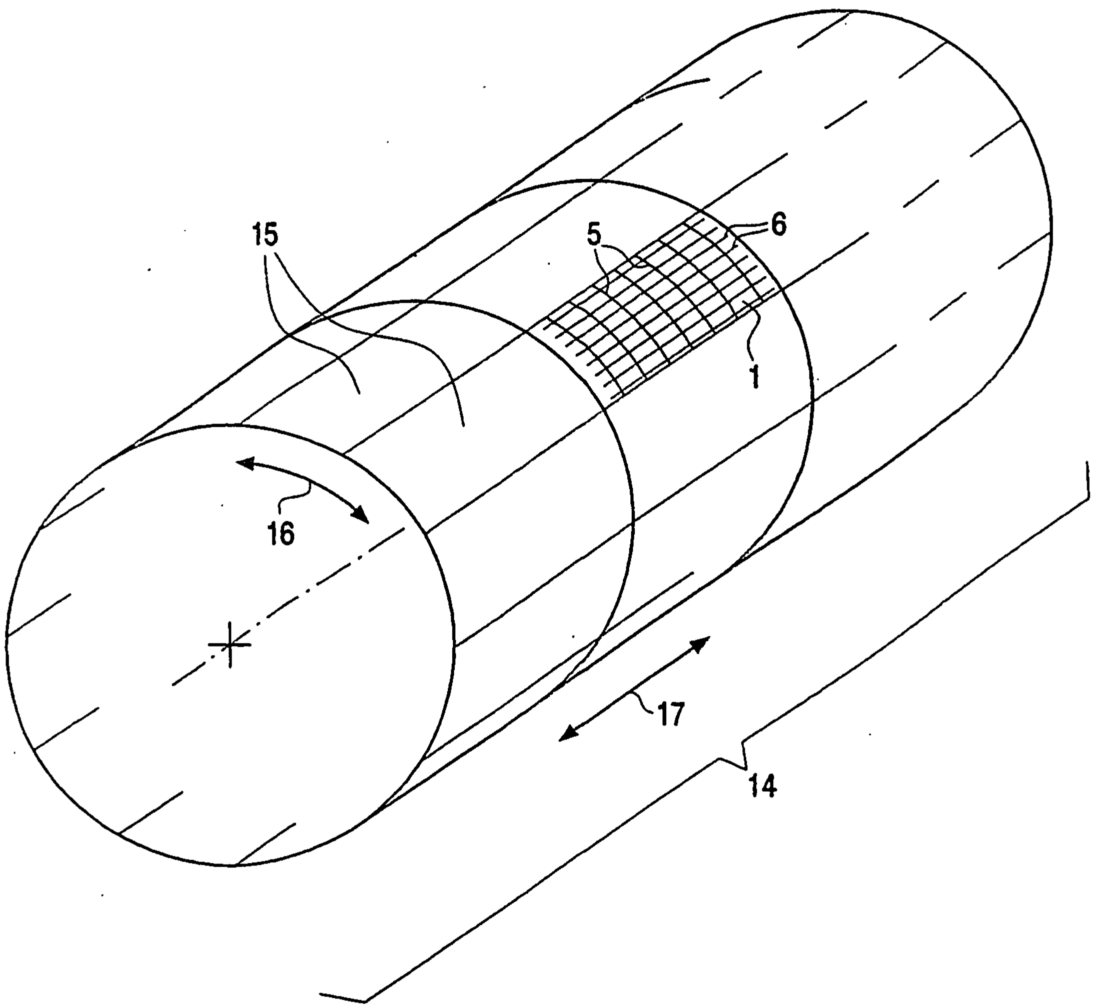
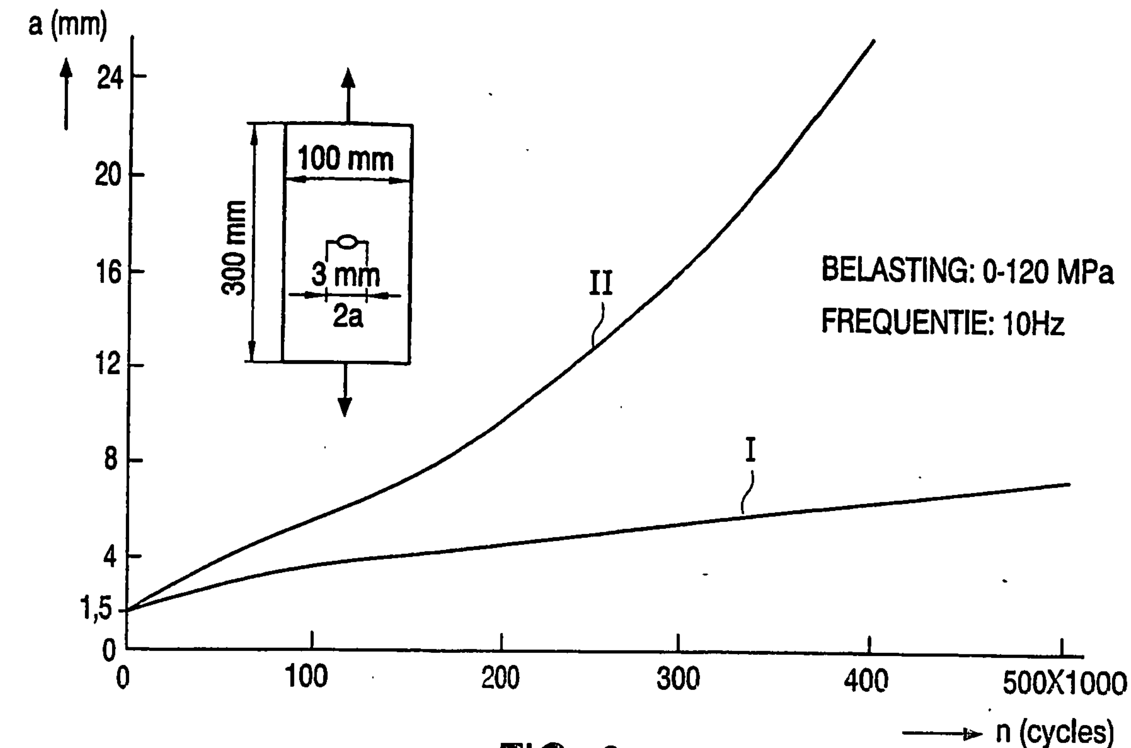
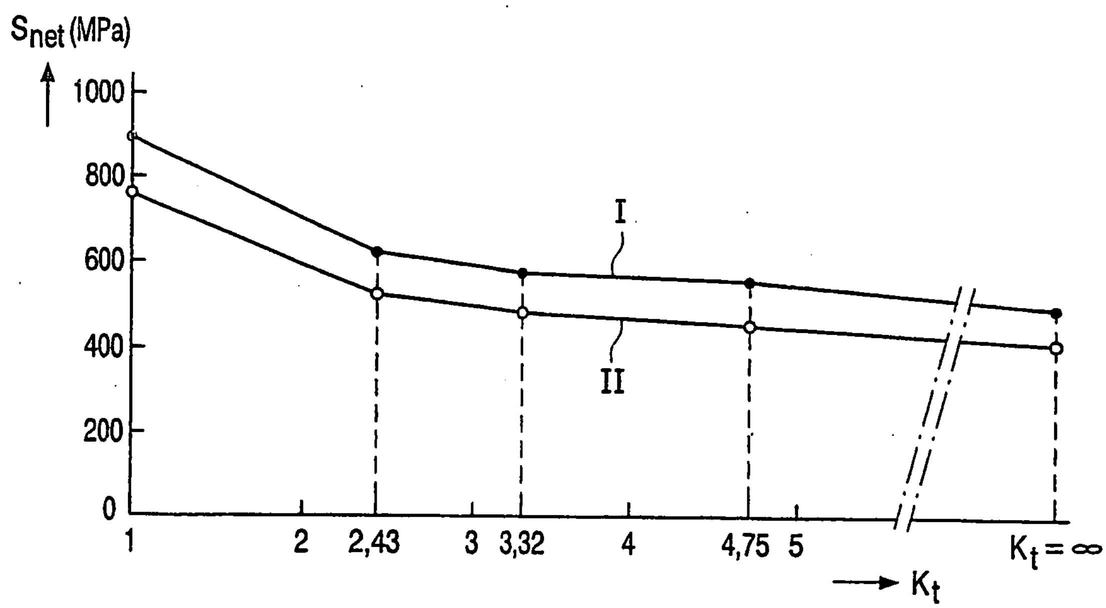


FIG. 8



a (mm)
24
20
16
12
8
4
1,5
0
100 mm
300 mm
3 mm
2a
II
I
BELASTING: 0-120 MPa
FREQUENTIE: 10Hz
0
100
200
300
400
500X1000
n (cycles)

FIG. 9



S_{net} (MPa)
1000
800
600
400
200
0
I
II
1
2
2,43
3
3,32
4
4,75
5
$K_t = \infty$
K_t

FIG. 10

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B32B5/26 B32B15/14 B32B5/02 B29C70/08 B29C70/88
B64C1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B32B B29C B64C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	NL 8 100 088 A (TECH HOGESCHOOL DELFT AFDELING) 2 August 1982 (1982-08-02) cited in the application claims & US 4 489 123 A (SCHIJVE ET AL) 18 December 1984 (1984-12-18) -----	1-16
Y	US 4 029 838 A (CHAMIS CHRISTOS C ET AL) 14 June 1977 (1977-06-14) cited in the application claims column 4, line 35 - line 41 column 3, line 53 - line 54 -----	1-16
A	DE 37 02 936 A (DORNIER GMBH) 11 August 1988 (1988-08-11) cited in the application the whole document -----	1-16

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 May 2004	28/05/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	De Jonge, S

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